Multidiscipline Utilization of the ISS Fluids and Combustion Facility

Microgravity Research Program Planning Meeting

Fluids and Combustion Facility

Bob Corban

February 10, 2000

GRC Microgravity Science Program

Fluids and Combustion Facility

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- **ISS/FCF/Payload Integration, Operations and Utilization**

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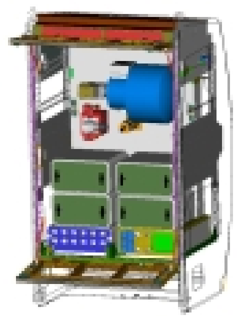
FCF Flight Segment

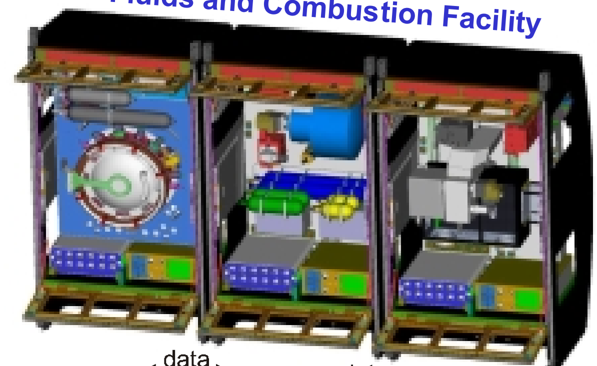
Combustion Integrated Rack (CIR) UF-3

Fluids Integrated Rack (FIR) UF-5



Shared Accommodations Rack (SAR) 2006

Fluids and Combustion Facility



Combustion Science Rack ◄ data ► **Shared Rack** ◄ data ► **Fluids Physics Rack**

CIR and FIR operate independently until SAR is deployed to ISS.

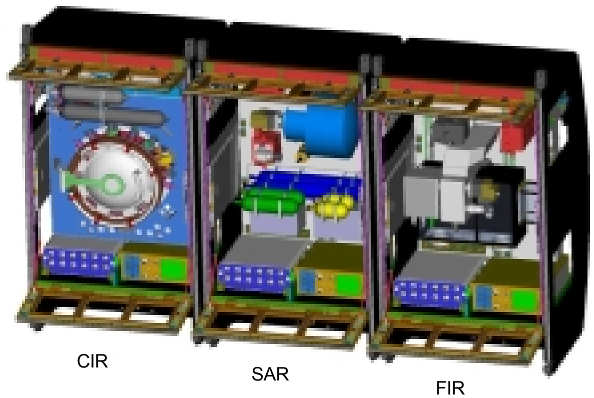
Assembly of FCF is completed by the addition of the SAR. Fluid Physics and Combustion Science disciplines then share racks and mutually necessary hardware/software.

FCF will accommodate all envisioned experiments at the rate of 10 or more per year for the lifetime of the Space Station.

1998	1999	2000	2001	2002	2003	2004	2005	2006
FCF HCR 6/98	CIR PDR 04/99	FCF PDR CIR CDR FIR PDR SAR PDR	FIR CDR	CIR Launch (UF-3)	FIR Launch (UF-5) SAR CDR			SAR Launch

Three-Tier Solution to Satisfy the Requirements and Constraints

Fluids and Combustion Facility

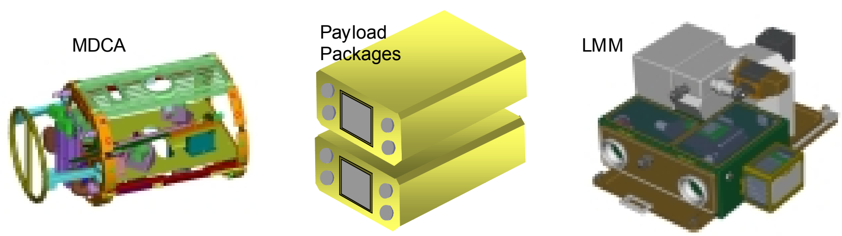


Tier 1

FCF Systems commonly needed by nearly all Fluids and Combustion Experiments

- Build once, launch once, use forever

Multi-Use Experiment Hardware

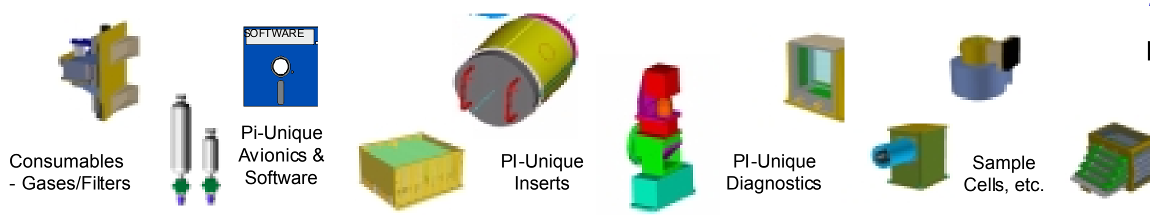


Tier 2

Multi-use experiment inserts customize FCF to a specific sub-discipline

- Build once, launch once per ~4 expts, reuse
- Other sub-disciplines reuse some equipment

PI Unique Equipment



Tier 3

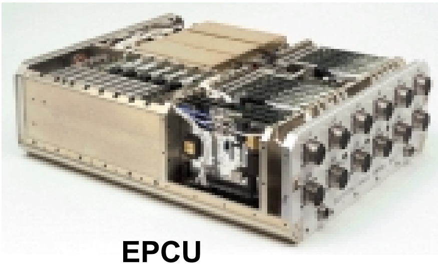
PI unique equipment

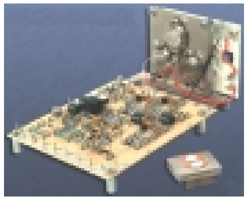
- Build and launch for each experi
- May reuse or add to capability of

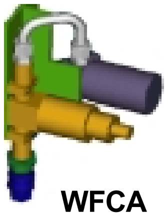
FCF Hardware Commonality

Electrical Power Control Unit[1]

- Interface to ISS power system provides fault protection and 120-to-28 VDC conversion
- 6 4-amp 120-VDC and 48 4-amp 28-VDC channels
- Capable of drawing from both input buses and prioritized load shedding, saving on-board resources
- Contract with Hamilton-Sundstrand to deliver one (1) qual. unit & seven (7) flight units. Unit cost: ~$600K


EPCU


Hybrid FRPC


WFCA

Water Flow Control Assembly[2]

- Controls flow of coolant water within FCF racks. Allows flow-leg balancing and finer control than ISS supply, saving on-board resources
- The flow range of the valve is 25 - 300 lbm/ hr. (Accuracy: +/- 3 Lb/ hr).
- Fixed price contract with Preece to deliver 24 units to FCF & 11 units to MSRR. WFCA recurring unit cost is $77K.

Payload Support Hardware

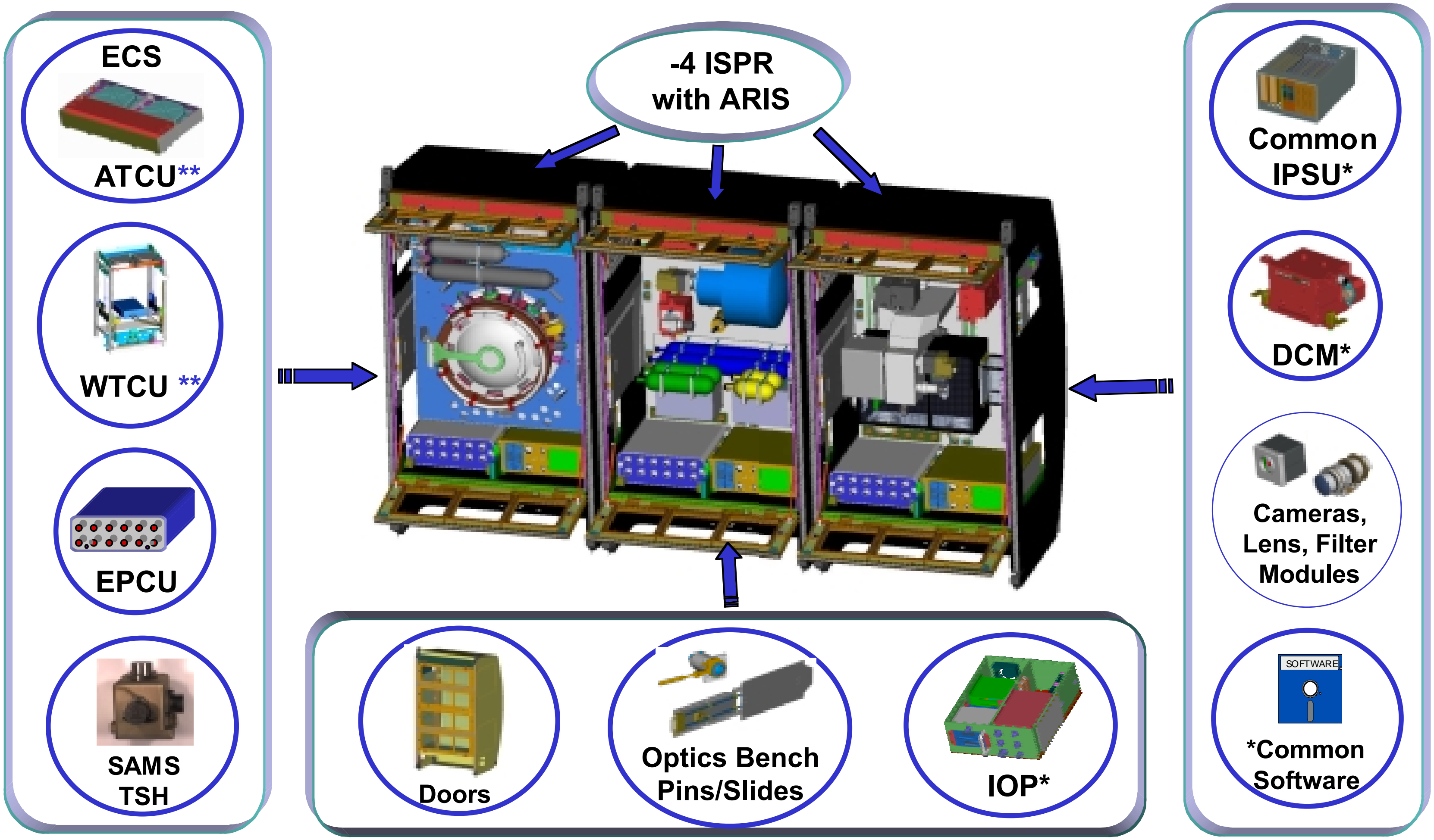
- ISS interface hardware procured from Boeing via MSFC NAS8-50000 contract.
- ISPRs, rack handling adapters, shipping containers, CIVT, HRDL board, smoke detectors, RMSA, electrical connectors and fluid QDs
- Effort ends September 2000 (pending deliveries)


Smoke Detector


ISPR

[1] - EPCU utilizes advance switching technology and is the basis for an alternate DDCU being developed for ISS.
[2] - Joint procurement with MSRF saved $750K

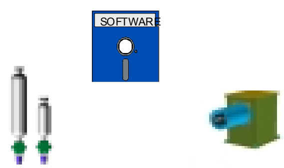
Common Hardware Use Reduces the Cost and Enhances the Performance of the FCF

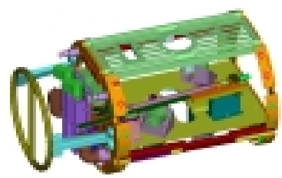


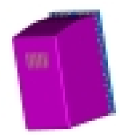
* Common ECS components such as fans, heat exchanger, filters, QDs, lines/hoses, GIS & FDSS hardware

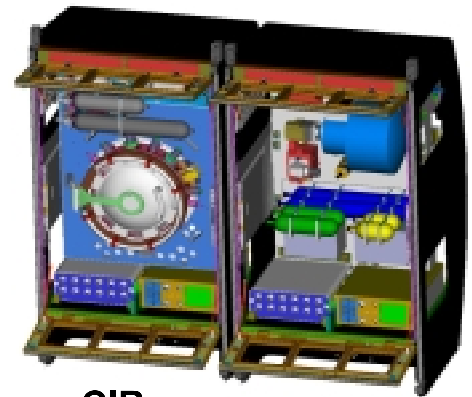
The FCF CIR/SAR Operate Together with PI Equipment as an Integrated System

The FCF provides support subsystems and diagnostics commonly used by most combustion experiments. Multi-user chamber inserts, avionics, diagnostics and other hardware/software customize the facility for specific combustion sub-disciplines. PI specific items such as fuels, oxidizers, consumables and unique instrumentation configure the facility to perform a given PI's research.









CIR

SAR

PI-Specific Items

- Fuels/Oxidizers/Consumables
  - Gaseous Fuels/Oxidizers
  - Liquid/Solid Fuel Supplies
  - GC check gases
  - Adsorber cartridge filters
- PI-Unique H/W & S/W
  - Specific avionics/software
  - Specialized diagnostics or modules (e.g., cameras, lenses, filters, optics, etc.)
- Specific Instrumentation

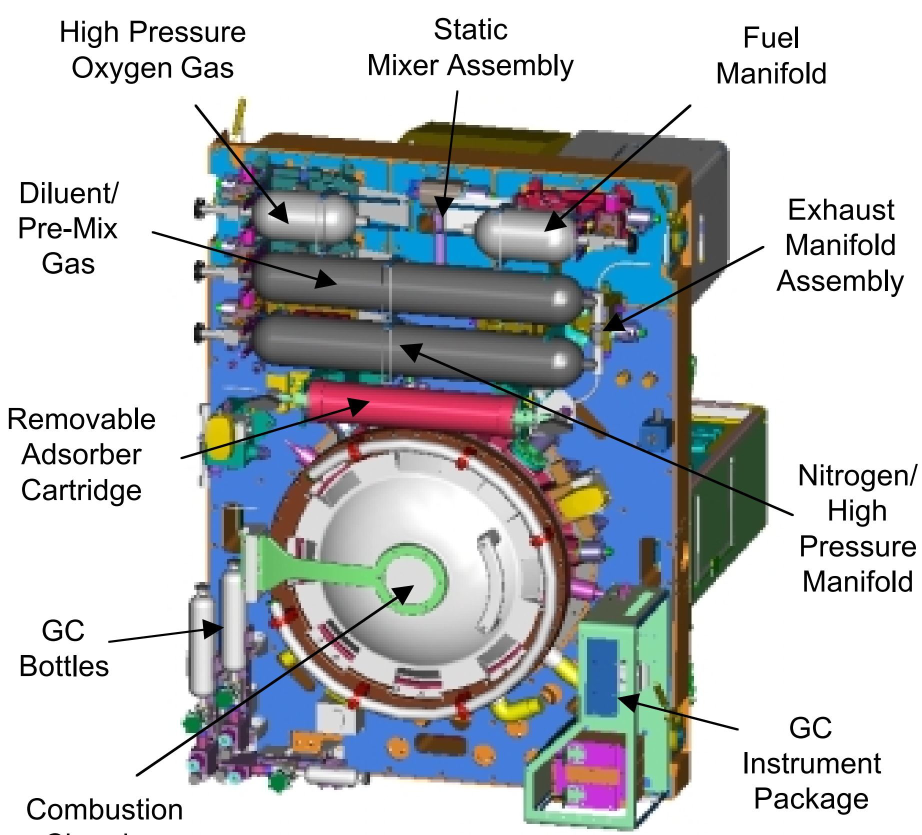
Multi-User PI Equipment

- Combustion Chamber Insert
  - Experiment orientation
  - Support structure
  - Flow ducts; test sections
- PI Avionics Package
  - Multi-use control electronics, motor drivers, etc.
  - Software modules
- Multi-Use Diagnostics / Lighting
  - e.g., Radiometers
  - PI-Unique illumination sources

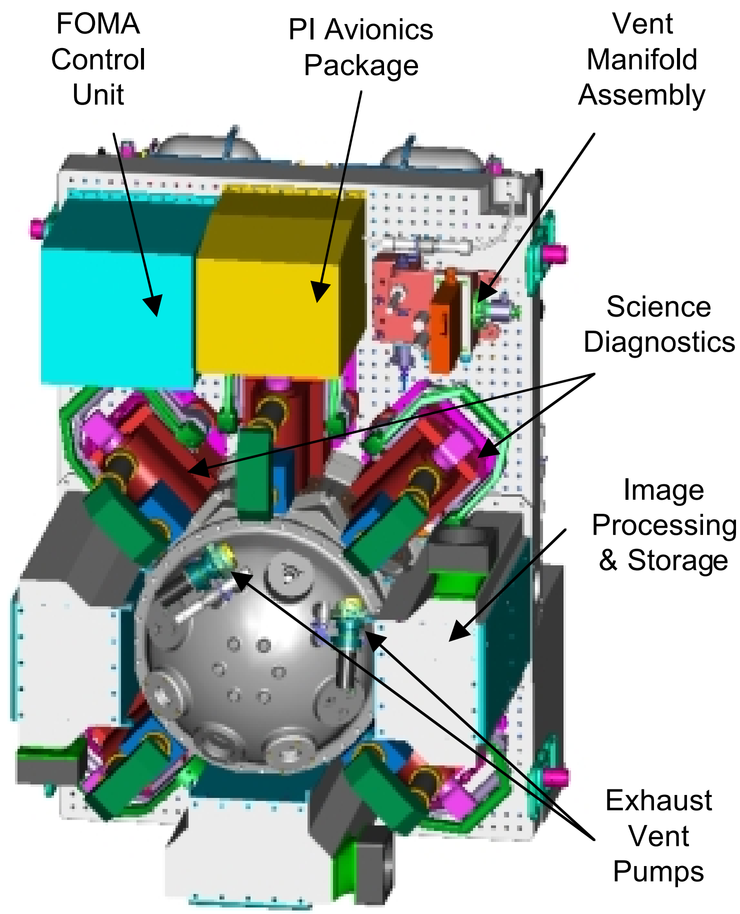
Combustion Integrated Rack/ Shared Accommodations Rack

- Combustion Chamber
- Diagnostics
  - 8 standard locations (w/ SAR)
  - Image Processing & Storage
- Gaseous Fuel/Oxidizer Mgmnt.
  - Gas Supply & Blending
  - Exhaust Vent / GC
- Electrical Power Control Unit
  - Power Conditioning & Control
- Command & Data Handling
- Active Rack Isolation
- Environmental Control
  - Water/Air Cooling
  - Gas Interface/Fire Detection

Equipment That Uniquely Supports Combustion Experimentation is Located in the CIR



(Front View)



(Rear View)

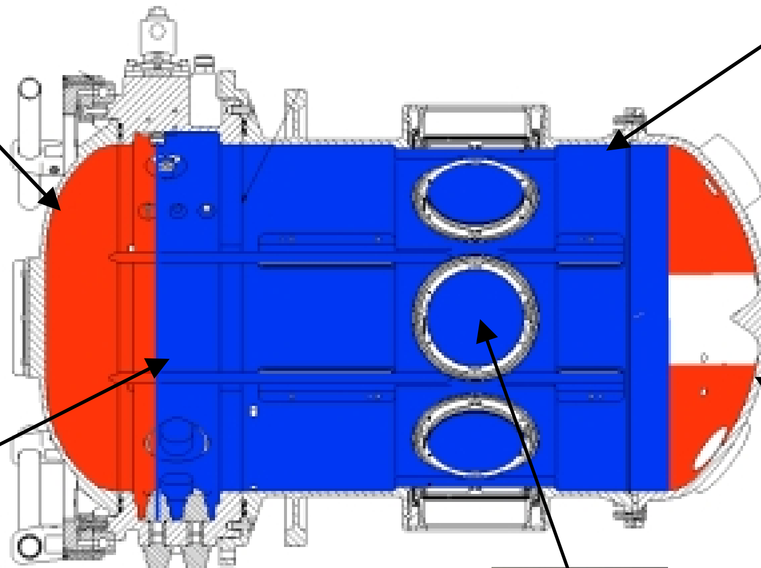
CIR Combustion Chamber Assembly

(with internal Experiment Apparatus
60 cm long x 39.6 cm dia.)

- **101 Liters volume**
- **120 psig MDP**

Chamber Front Lid with Breech Lock
(With breech, crew can open chamber in minutes -- versus hours for previous experiments)

Chamber Window Section -- 8 Windows
(Only six can be used until SAR)



Interface Resource Ring
(power, cooling water, gas supply/venting & data interfaces with experiment insert)

Replaceable Windows
(11.5 cm FOV)

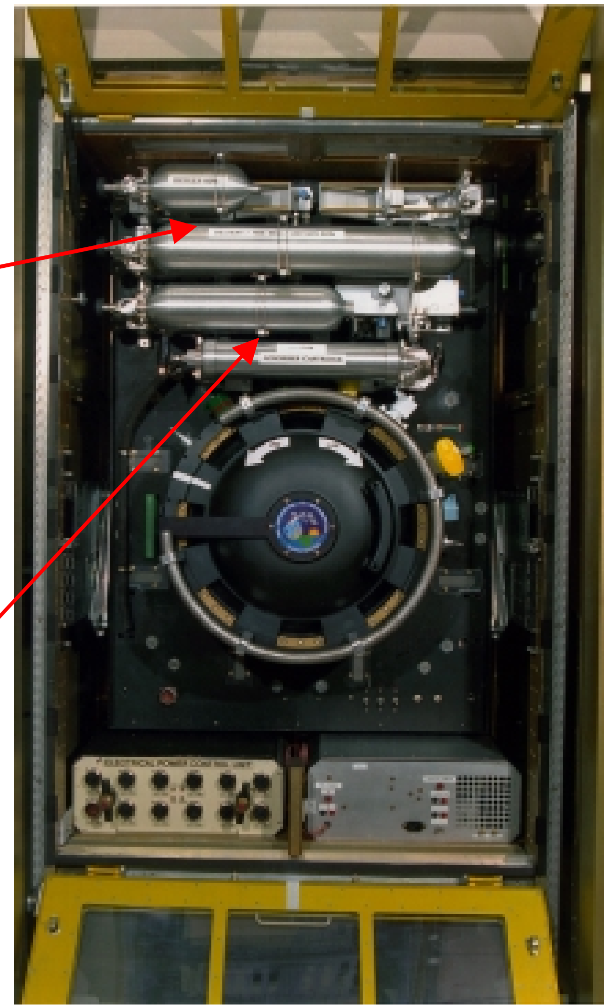
Chamber End Cap
(instrumentation & axial imaging)

- Fused silica windows used for visible imaging. Sapphire windows for near IR and Zinc Selenide for mid-IR imaging.
- Sixteen (16) orthogonal views to image combustion experiments are possible in the CIR (after SAR is deployed).

Fuel/Oxidizer Management Assembly (FOMA)

- **Gas Supply and Distribution Package -- delivers gaseous fuels, diluents and oxidizers to the combustion chamber**
  - Gases supplied in 1.0, 2.25, 3.8 liter removable bottles
    - Maximum bottle pressure is 14 MPa (2000 psi)
    - Can accommodate pre-mixed gases
    - 3 manifolds at 30 SLM per, yields 90 SLM total gas flow.
  - On-orbit gas blending of up to 3 gases
    - Partial pressure or dynamic gas blending
    - On-orbit gas blending weight savings: <u>Factor of 4</u>
  - Design permits flow-through with real time venting
  - Interfaces with ISS nitrogen supply are provided
- **Exhaust Vent Package -- cleans/vents the chamber gases**
  - Adsorber cartridge/re-circulation loop cleans post-combustion gases to ISS limits with a max flow of 20 SLM
  - Adsorber Cartridge may contain: silica gel, molecular sieve, activated carbon, lithium hydroxide, or others.
  - Exhaust Vent Package connects the combustion chamber with the ISS vacuum exhaust system (VES)

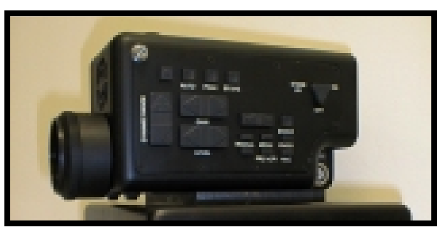
– **3 Column Gas Chromatograph -- samples combustion chamber**
  - Molecular Sieve: fixed gases (He, H_2, O_2, N_2, CH_4, CO) 100 ppm -100%.
  - PoraPLOT Q: light hydrocarbons, CO_2 and SF_6 15 ppm - 100%.
  - OV1701: low MW alcohols and C+ hydrocarbons, 15 ppm – 100%



CIR Provides Standard Science Diagnostics and Illumination Sources for Experiments

Low Light Level Packages (UV and IR)
- 6 - 30 cm diagonal FOV
- 5X zoom capability
- 60 Frames per second
- UV package uses industry standard Gen II intensifier
- IR package uses industry standard Gen III intensifier

Illumination Package (provides 3 Illumination sources)
- Tungsten Halogen source
- Diffuse Laser Diode source
  - 10 mw coupled power
  - 675 nm peak wavelength
- Coherent Laser Diode source
  - 5 mw coupled power
  - 675 nm peak wavelength

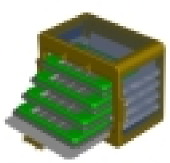


Mid-IR Camera Package
- 183 mm x 138 mm FOV
- Automatic focus
- Spectral range: 3600 - 5000 nm
- 320 X 244 pixel elements
- Temperature Measurement Accuracy: +/- 2% or 2^{o}C

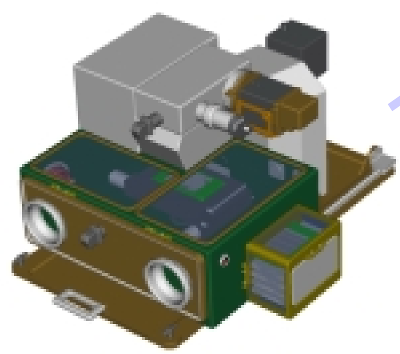
Breadboards of standard CIR Science Diagnostics are shown

Integrated FIR/SAR Concept

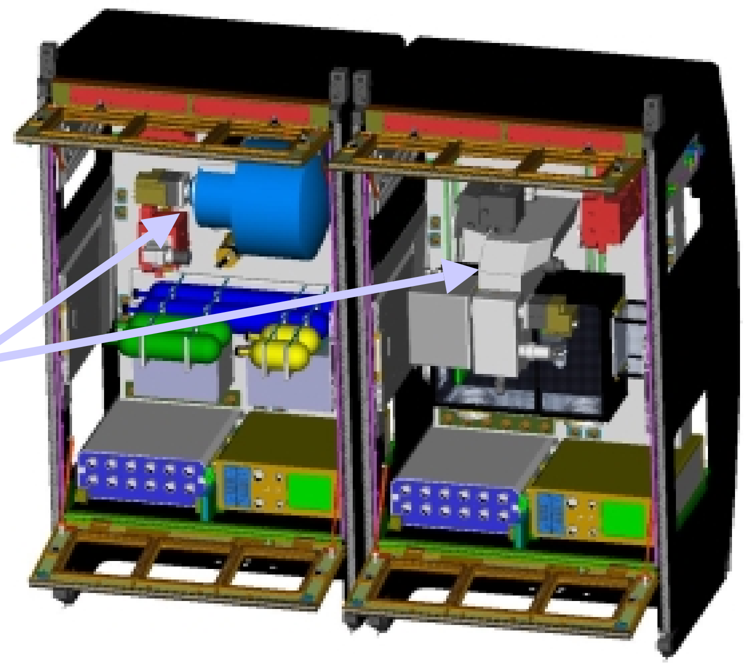
The needs of the Fluid Science community are met on the FCF with a combination of FIR, SAR, and PI unique hardware.



PI Specific Samples

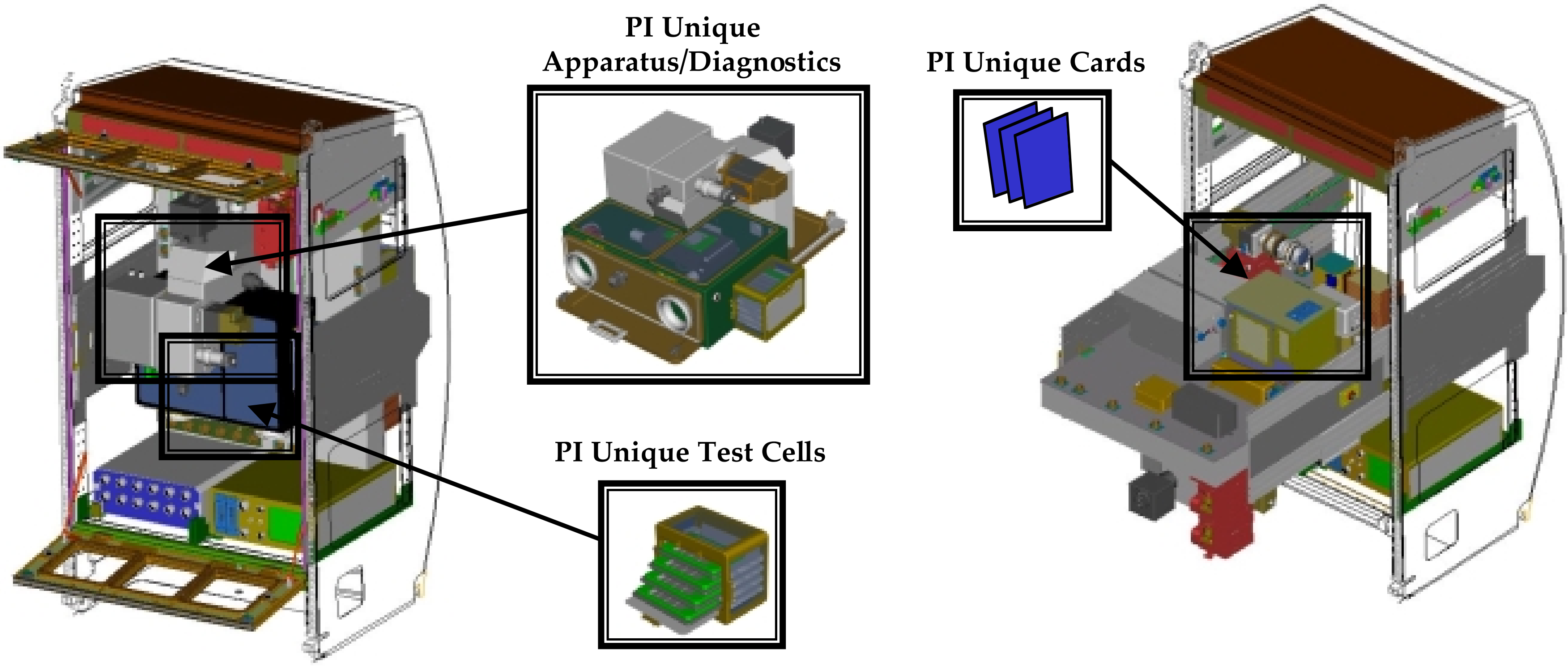


Investigation Module



Fluids Integrated Rack/ Shared Accommodations Rack

FCF/FIR Customized for Each New Fluid Physics Experiment



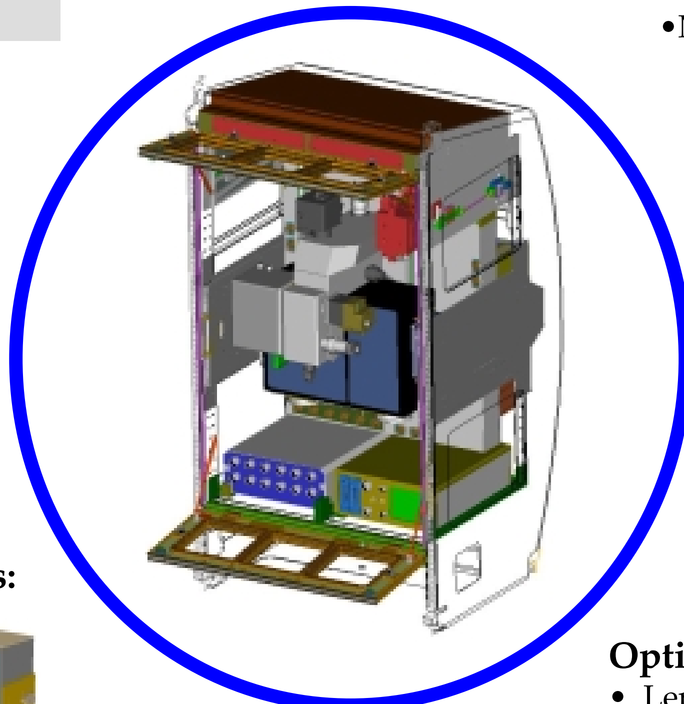
Commonly needed equipment, optimized for fluid physics experimentation, remains on-orbit and reconfigured

PI unique equipment customizes the FIR to do the required science

FIR Accommodations

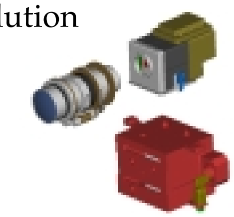
FIR Features:
- Easy access via fold down bench
- Diagnostics easily reconfigured, replaced/interchanged on optics plate
- Accommodates many experiment configurations and disciplines

Image Processing & Storage Units
- Two Independent Image Processors
- Support for High Resolution Digital Camera
- 18.2 GB Hard Drives
- Data Compression
- Motion Control for APT/Focus/Zoom

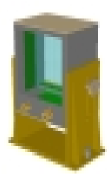


Basic Services
- PI Volume: 460 liters
- Rotating Optics Bench
- Electrical Power
- Remote Operation Capability
- Environmental Control
- ISS Command and Data Interface
- Control/Timing

Cameras:
- Color Camera
- Hi Resolution



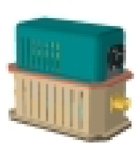
Illumination & Laser Packages:
- White Light via fiber Weave
- LED Array
- Laser Diodes
- Nd: YAG
- HeNe (optional laser)



LED Array

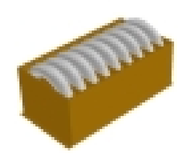
Optical Components:
- Lenses
- Collimators
- Fiber optic cables
- Mirror

Laser Diodes

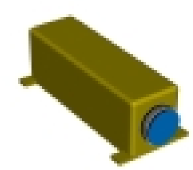


Nd:YAG

HeNe Laser (optional)

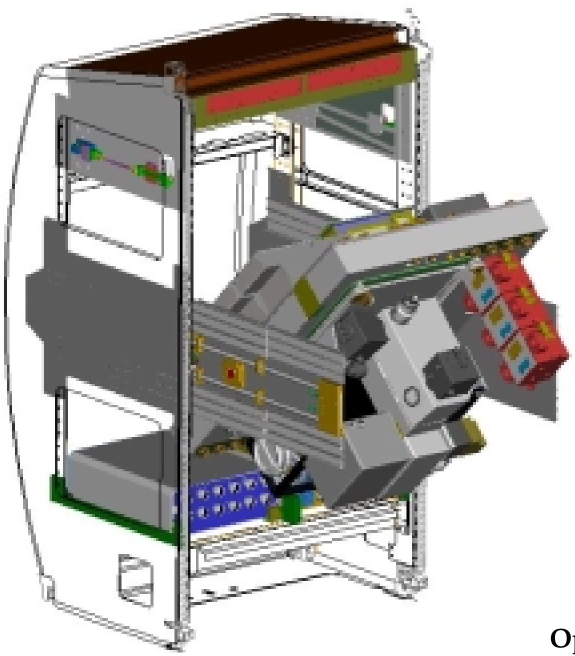


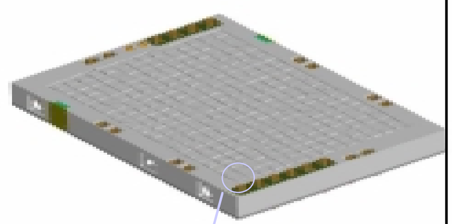
Optical Fibers



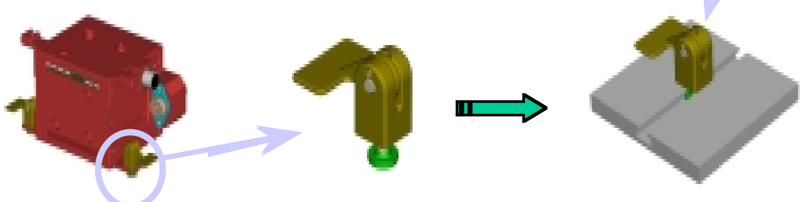
Collimating Optics

Fluids Rotating Optics Bench Package:





Optics Plate Rail Design



Quick connect assembly attached to baseplate of package

Quick connect assembly mounted in optics plate rails

Platform for PI hardware

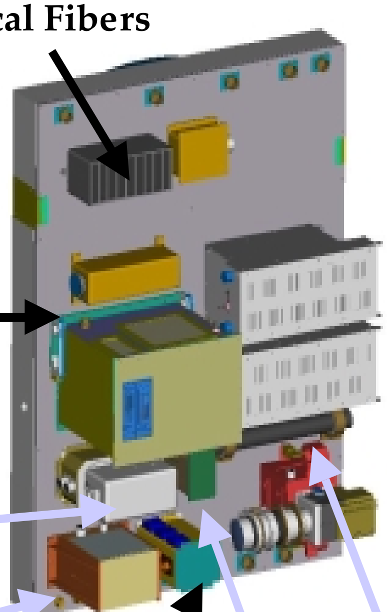
- –737mm x 1016mm front bench dimensions
- –460 liters available volume for PI hardware
- –Allows for infinite reconfigurability for PI hardware custom set-up

Rotating bench for ease of access to back of bench

Internal Rail Design

- –High accuracy positioning, 2mm and 2 degrees point to point
- –Flatness <0.5mm
- –Quick connect interface for easy crew interface

Laser Packages & Illumination:



Nd: YAG

- –532nm Wavelength, solid state laser
- – > 50mW Power to PI hardware
- –Coherence Length ~30m
- –Linearly Polarized
- –Stability +/- 1% over 8 hours

HeNe (optional laser)

- –633nm Wavelength
- –single mode, 1mW Power
- –Polarization ratio 500:1
- –Application: interferometry

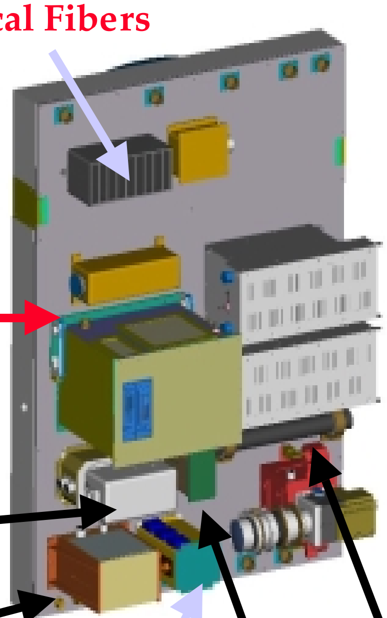
Laser Diodes

- –680 nm, 10mW and 780 nm, 15mW
- –Supplemental laser diode drive available for PI hardware

LED Array

- –150mm x 150mm, 640nm illumination strobing capability, variable intensity

Laser Packages & Illumination (cont.) :



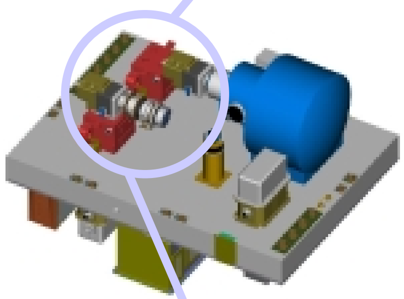
Optical Fibers
- Polarization Maintaining
- Wavelength Matched

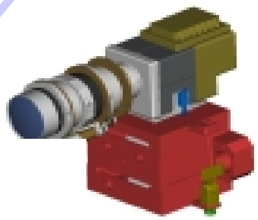
Collimating Optics
- 2.5 mm beam, <1.5 milliradians divergence
- 50mm beam, <0.8 milliradians divergence

White Light Source
- 140mm x 140mm fiber weave panel
- Highly uniform intensity

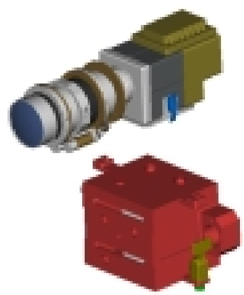
Mirror
- Gimbal Mounted 6 axis of rotation
- Remotely controlled
- Use in automated position and tracking

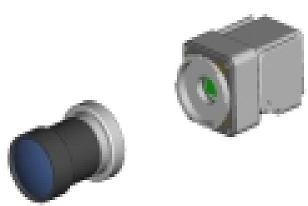
Cameras and Lenses:





High Resolution Camera, with modular design





Color Camera Body and interchangeable lens

High Speed Cameras
- 1024 x 1024 12-bit pixels up to 30 fps

High Resolution Microscopic Camera
- 8x magnification for 1 mm x 1mm field, 3 micrometer resolution

Color Camera
- 484x768 pixels
- 3 chip design for individual R,G,B readout
- C-mount lens for interchangeability

Ultra- High Speed Camera (Generation II)
- 1000 fps w/ significant longer duration and higher resolution
- Enhanced Image Processing & Storage Unit

Macroscopic Zoom Lens
- 19mm - 100mm Fields of View (FOV)

Microscopic Lens
- 200um x 200um FOV - 18mm x 18mm FOV

Data Acquisition Functions

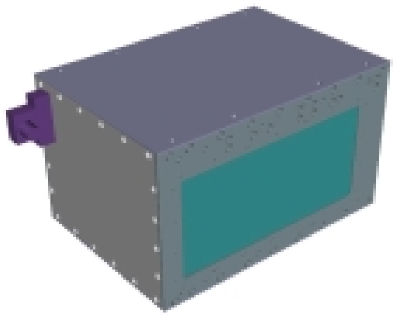
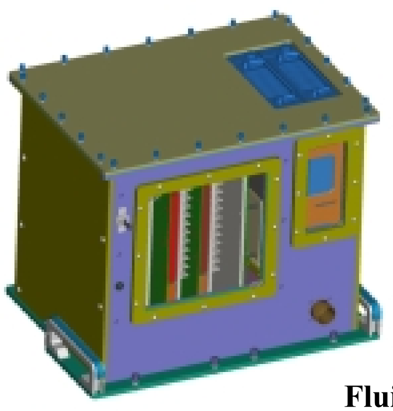


Image Processing Unit (2)



Fluids Science Avionics Package

Dual Backplane:
8 Slots CPCI
(3U Form Factor)

Imaging Processing Capabilities

–Two Independent Image Processors

–Support for High Resolution Digital Camera

–18.2 GB Hard Drives

–Data Compression

–Motion Control for APT/Focus/Zoom

–Two Image Processing units in FIR, with additional units available in SAR

Fluids Science Avionics Package for PI Hardware Use

–400MHz Pentium III CPU

–Ultra2 Wide SCSI interface

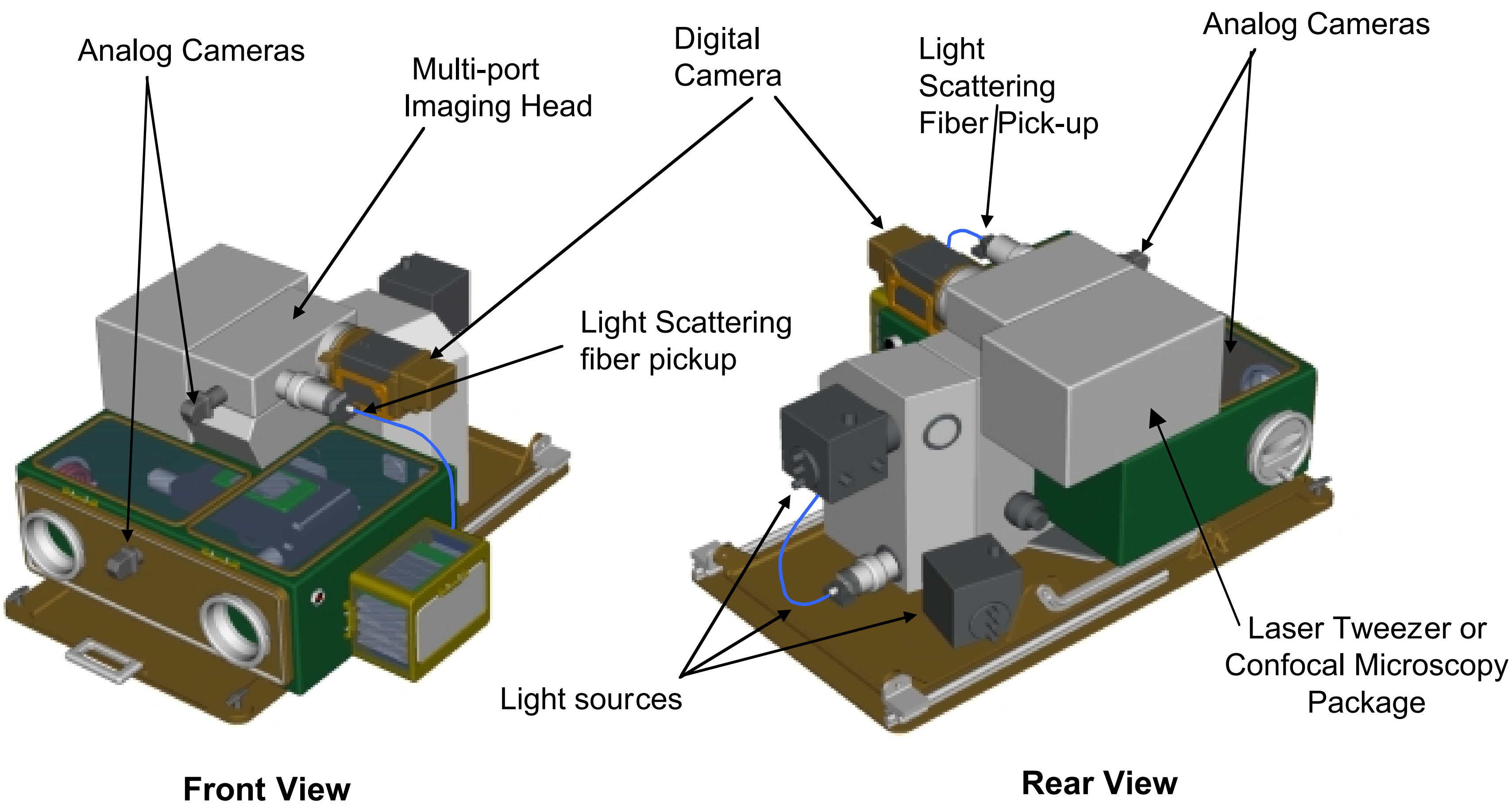
–Analog video signals such as NTSC, PAL, RS-170, or RGB at a rate of 30 frames per second.

–Motion Controllers –2 channels of Stepper Motor Control and 2 channels of Servo Motor Control.

–Input/Output Channels for Science - 48 channels of digital I/O, sampling rate of 67 kHz.

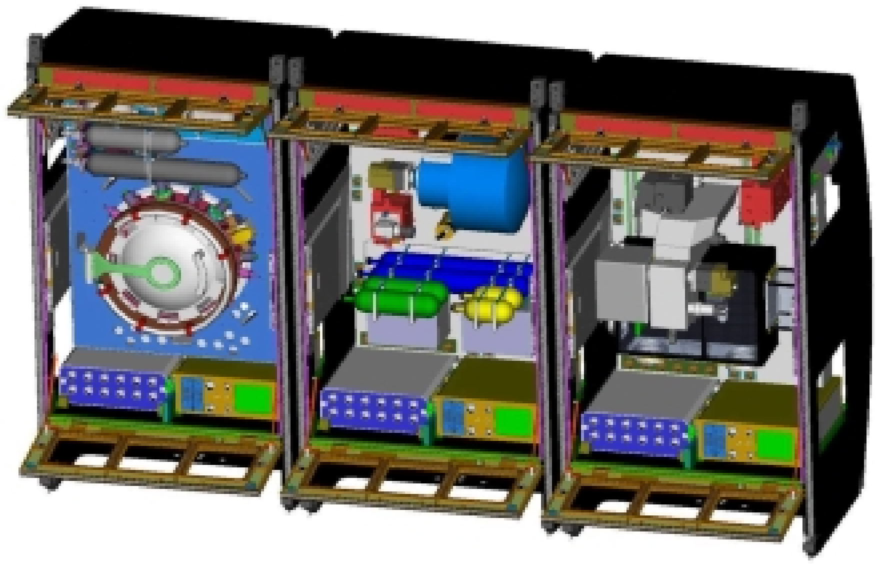
–CAN Bus– Provides 2 channels; 1 for PI use and one for the common internal rack use.

PI Specific Hardware - Light Microscopy Module

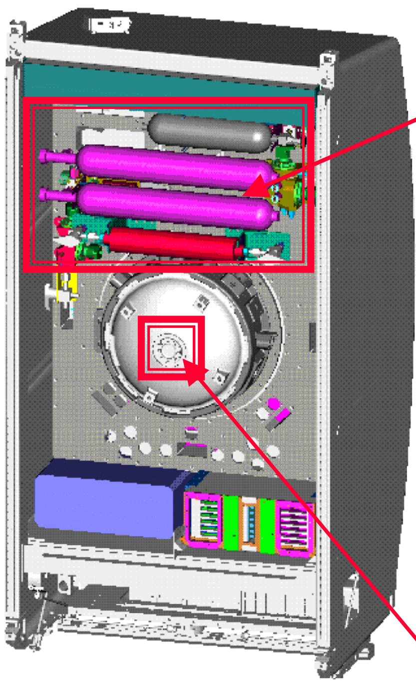


Multi-Discipline Use of the FCF

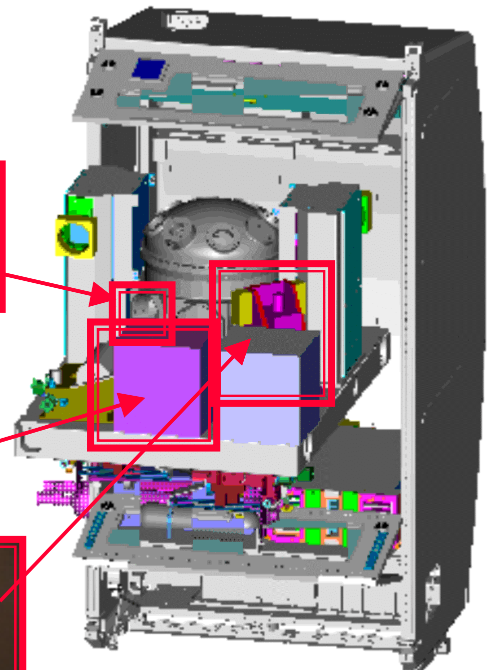
- **FCF Capabilities**
  - Provides state of the art imaging capabilities: High resolution, high data rate
  - Provides image processing and mass storage.
  - FCF imaging systems can be reconfigured to meet the needs of specific experiments.
- **CIR Capabilities**
  - Provides containment to experiments.
  - Gas delivery system which accommodates a wide variety of gasses.
  - Provides controlled venting.
  - Eight diagnostics locations for imaging inside the chamber.
- **FIR Capabilities**
  - Provides a large contiguous volume which can support a variety of experiment configurations
  - Supports frequent experiment reconfiguration.
- **SAR Capabilities**
  - Accommodates two double middeck lockers
  - Provides services equivalent to MDL interface in express
  - Provides powered sample preparation area.



FCF Racks are Customized with Multi-User and PI Unique Experiment Equipment



PI unique gases & filter



PI unique windows, if required.

Multi-user PI computer

Multi-user or PI unique diagnostics

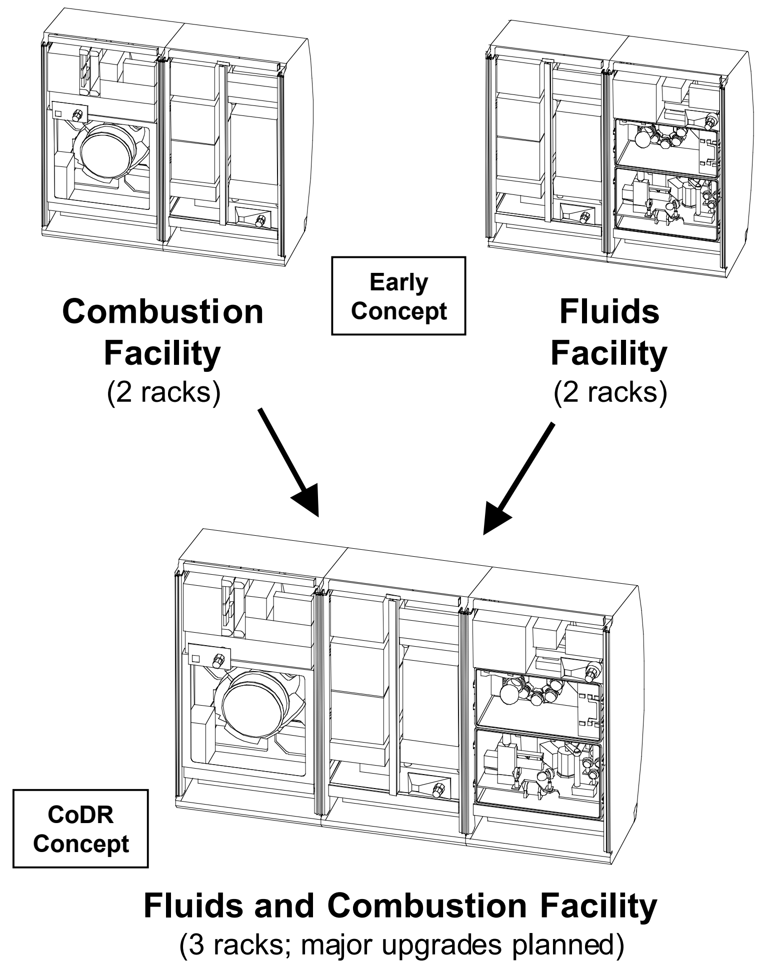
Commonly needed equipment, optimized for experimentation, remains on-orbit.

Multi-user or PI unique experiment insert

Multi-use and unique PI equipment customizes FCF to do the science -- but low volume, mass, crew time, and cost relative to non-facility approach.

FCF Project History

- Study efforts for microgravity fluids and combustion facilities began in 1987.
- Early concepts called for separate Combustion and Fluids Facilities, each using 2 racks (4 racks total).
- The two facilities merged into a single, multi-discipline facility in 1991. The facility was reduced to three racks with the center, core rack being a shared rack.
- In 1992, the Combustion Module (CM-1) spun-off as a separate project as a pathfinder to an ISS facility. CM was developed and flew in Spacelab, supporting two (2) PI experiments.
- In 1993-94, Science Requirements Envelope Documents were endorsed by the Fluids and Combustion Discipline Working Groups.
- A Conceptual Design Review of the FCF was held in December 1994. The FCF CoDR concept would support 4 PI's per year with major facility upgrades planned.



Facility Design Challenge

Spacelab Combustion Module

- Pathfinder for ISS Fluids & Combustion Facility
- CM occupies two (2) SpaceLab racks
- Total equipment volume ~4 m3
- Total equipment mass ~730 kg
- About two (2) weeks on-orbit, then return to Earth to refurbish and reconfigure for reflight
- Two (2) PI's supported (CM-1)* *3 PIs planned for CM-2

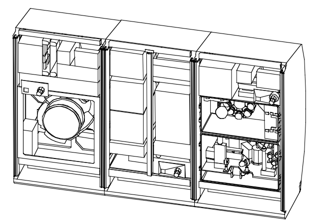
ISS Fluids and Combustion Facility Combustion Element/CIR

- Permanent, multi-user facility payload rack
- CIR occupies one (1) ISPR
- ISPR volume ~1.6 m3
- CIR mass w/ PI hardware 1000-1100 kg
- More than 10 years on-orbit with no rack change out or return to Earth (*Modular/flexible design*)
- Support >50 PIs over 10 yrs (*SAR is needed*)

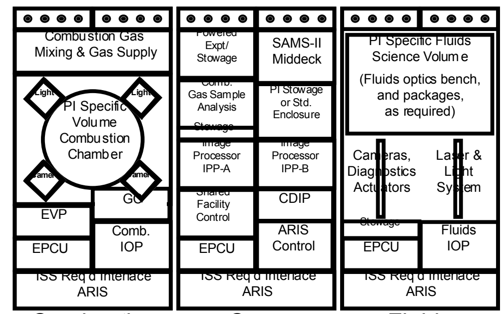
FCF Project History (Cont'd)

- A Code U Research Facility Assessment Team (CURFAT) reviewed the FCF in April 1995
- In 1995, the FCF was re-architected to emphasize a flexible/modular design, automated functions, and other features that would reduce cost and increase PI throughput while operating within realistic ranges of ISS resources that were becoming evident.
- A Space Station Facility Assessment Review (SRFAR) of FCF was held in May 1996.
- A Requirement Definition Review of the FCF was held in October 1996 to review the science requirements envelope (SRED) and the feasibility of FCF to meet science requirements.
- In 1997, in response to ISS payload funding cuts and assembly sequence changes, the FCF was re-architected to permit deployment of initial, integrated racks (CIR/FIR).
- These FCF modifications were reviewed and endorsed at a Hardware Concept Review held in June 1998.

CoDR Concept



RDR Concept



HCR Concept

Combustion Integrated Rack

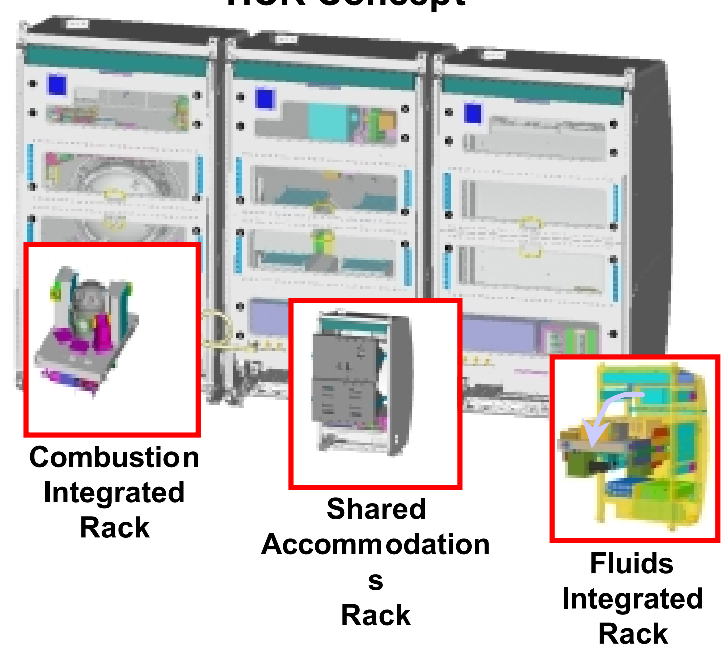
FCF/SAR

Fluids Integrated Rack

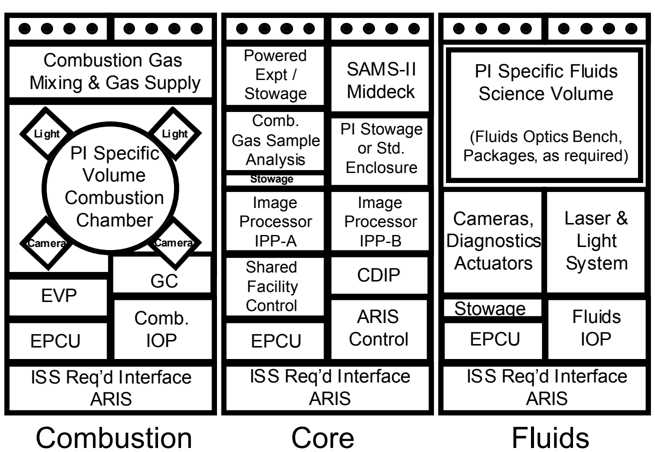
Three Rack FCF Adapted to Launch One Rack at a Time

- **CIR, FIR and SAR Incorporate Optics Benches**
  - Diagnostics easily reconfigured, interchanged, replaced
  - Benches permit FCF to accommodate various experiment geometry's and configurations (i.e., ranging from pre-packaged payloads to custom layout).
  - Experiments may be run in the CIR, FIR or SAR.
- **Emphasize Modular Flexible Facility Design**
  - Avionics modules which initially reside in CIR/FIR (i.e., to permit independent rack operations on-orbit) relocated to the SAR.
  - Bench interfaces permit flexible positioning of experiment hardware and diagnostics to other FCF rack locations.
  - Embedded web new technology applied to FCF.

HCR Concept



RDR Concept



FCF Changes -- RDR to HCR:
- Allow for deployment or initial, interim fluids and combustion racks to address subset of SRED for initial payloads.
- Scar for three-rack facility operation. When FCF/SAR is deployed, address full scope of SRED requirements.

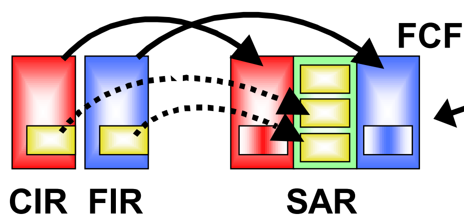
FCF Performance Requirements

Performance Requirement: After FCF assembly complete, accommodate an average of 10 PI *Basis Experiments** per year, including operations, maintenance & failures within resources and constraints. As resources are increased, accommodate up to 30 experiments per year.

Principal Resources and Constraints:** FCF Budget, PI Hardware Budget, Operations Budget, Astronauts crew availability 4-12 hrs/expt, Power <1000-2000 W nominal, cooling marginal relative to available power, relatively low downlink rate, up mass 25-75 kg/PI, limited on-orbit stowage.

Launch Sequence

CIR	UF-3
FIR	UF-5
SAR	LF-?



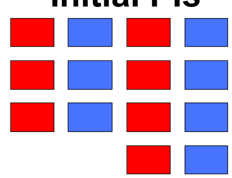
When SAR launches, shared hardware is located in the center rack. Science hardware is added to the fluids and combustion racks.

Develop

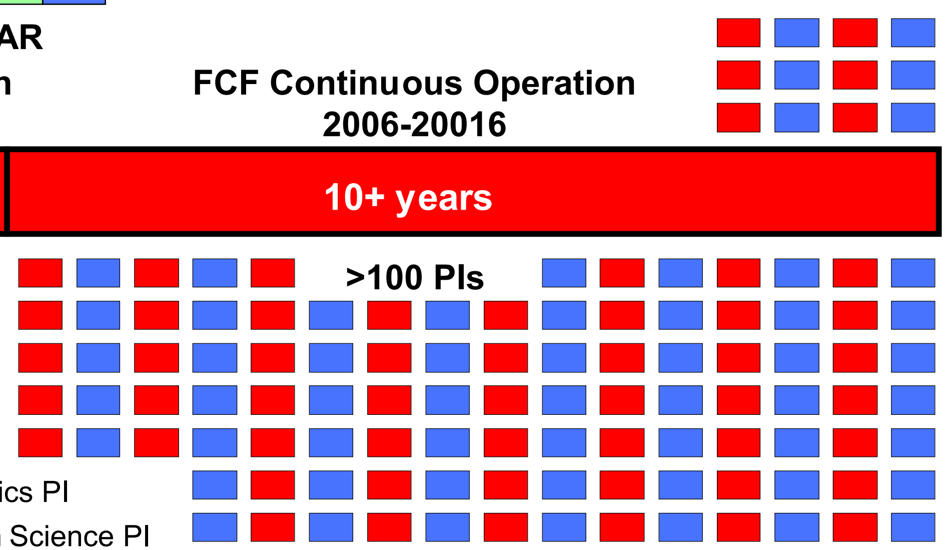
Interim Operation 2003-2006 — **~3 years**

FCF Continuous Operation 2006-20016 — **10+ years**

Initial PIs



>100 PIs



Fluids Physics PI

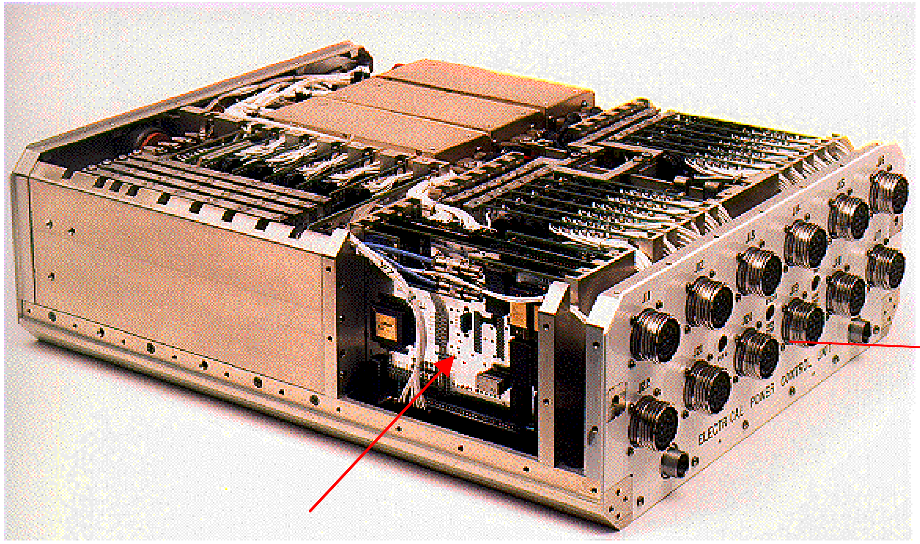
Combustion Science PI

* The SRED describes 25 Basis Experiments. FCF shall be able to perform >80 percent of them.

** Estimated resource allocations for FCF

FCF Electrical Power Control Unit Hybrid Switch Technology

FCF Electrical Power Control Unit (EPCU)

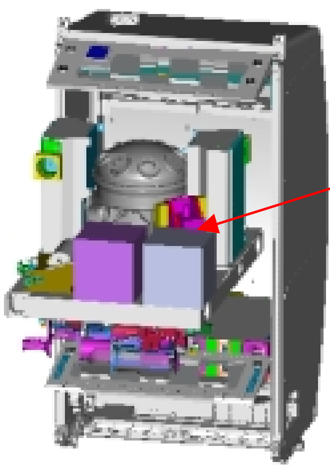


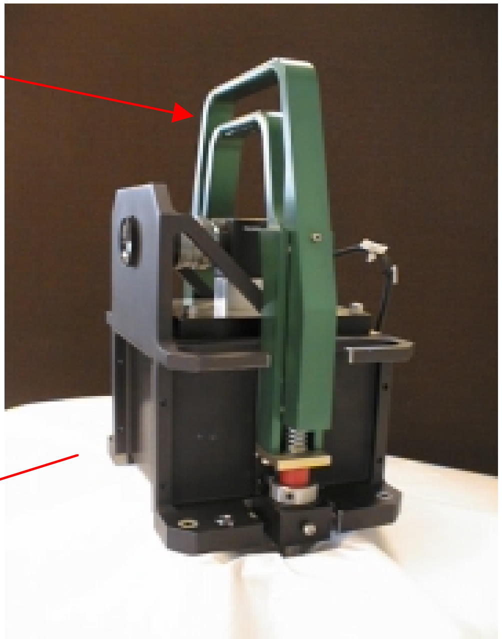
~100 Hybrid Switch Units in each EPCU

Hybrid switches developed by FCF with Sundstrand are next generation current limiting power switches that solve many issues relating to Space Station, Satellite, Aircraft, and other aerospace power switching applications. They are being considered for TransHab, Russian equipment, ISS DDCU upgrade and other aerospace applications besides FCF.

Quick Disconnect System for Complex Electronics

Squeeze handle to engage or disengage power, signal, and precision mechanical alignment[1]

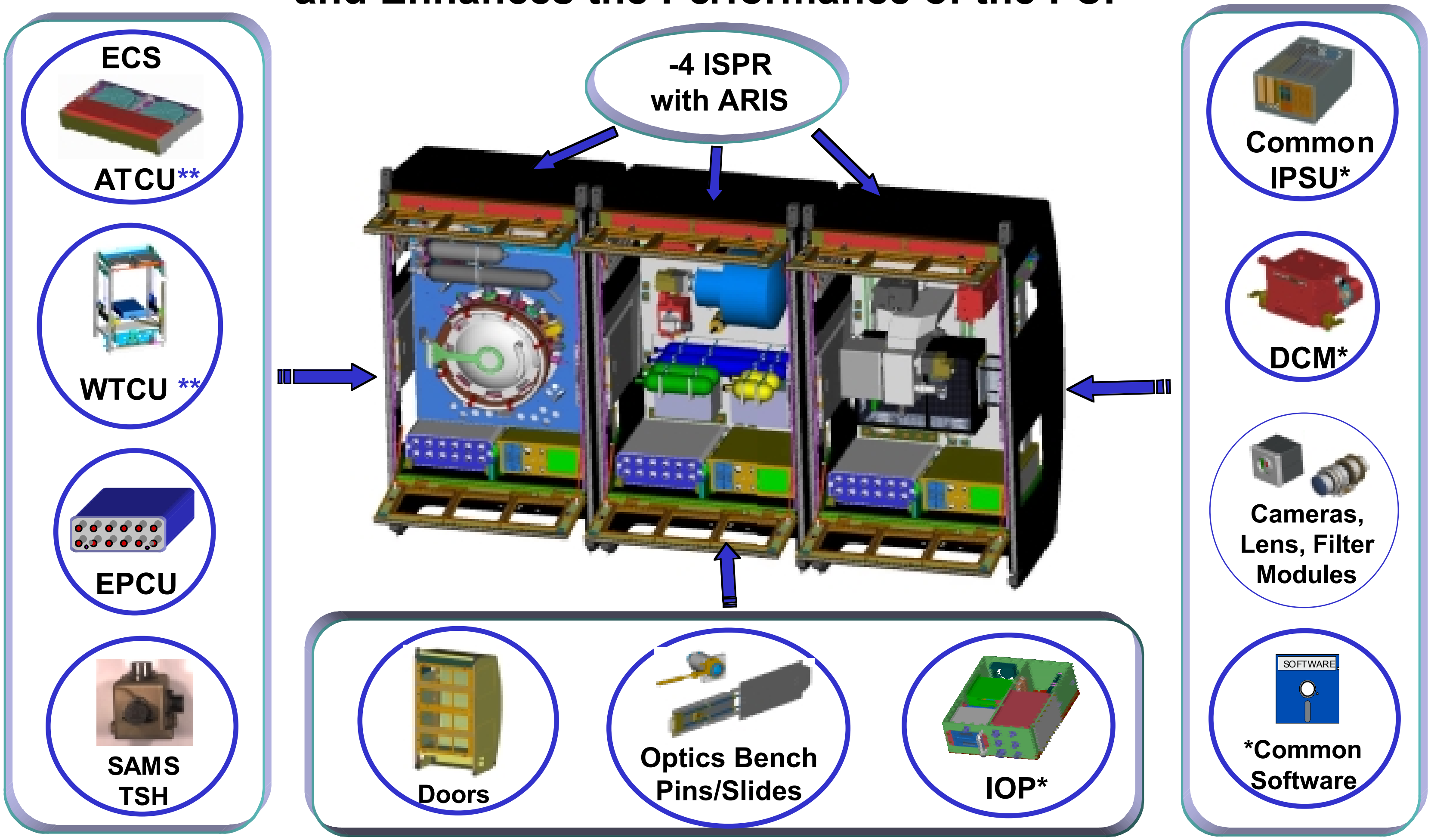




FCF uses system to allow Astronauts to install and align cameras in FCF 100 times faster than in previous experiment hardware.

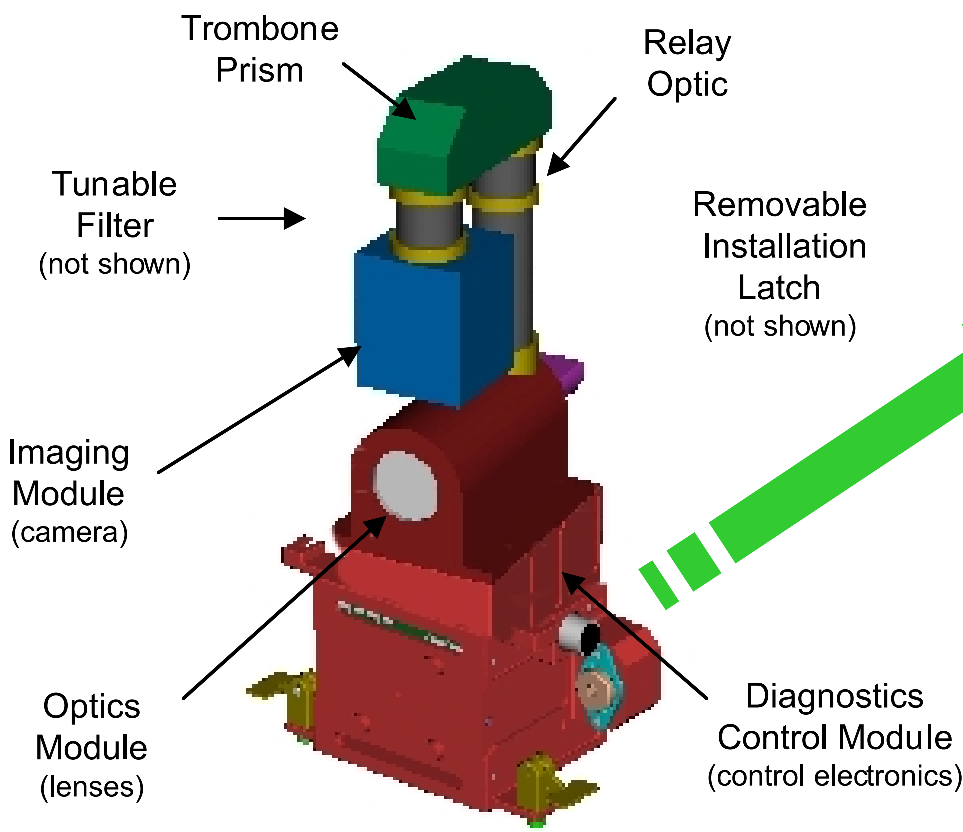
1. CIR quick disconnect system shown provides for power, signal (data) connections and mechanical alignment via attachment at fixed Universal Mounting Locations (UML) on CIR optics bench. Optics plate rail design and quick connect assemblies on FIR packages permit flexible layout of experiments, rapid installation and easy reconfiguration of FIR for fluids experiments.

Common Hardware Use Reduces the Cost and Enhances the Performance of the FCF

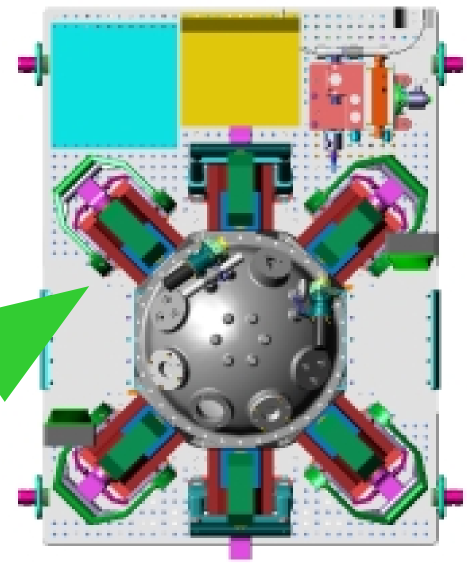


* Common ECS components such as fans, heat exchanger, filters, QDs, lines/hoses, GIS & FDSS hardware

FCF Science Diagnostics are Modular for On-Orbit Reconfiguration, Replacement or Sharing by Fluids/Combustion Disciplines



High Frame Rate/High Resolution Science Diagnostic ORU



CIR Optics Bench (Rear View)

- DCMs mount on optics benches in CIR, FIR or SAR.
- Cameras, lens, filters, reflective optics, relay optics, other diagnostic modules may be exchanged between FCF racks.
- Modularity and standard interfaces permit technology upgrades and/or tailoring of FCF-provided diagnostics to meet PI specific needs.

Summary

- **FCF is designed to fit within the envelope of requirements and constraints**
  - Three tier approach -- FCF, multi-use PI hardware and PI unique hardware
  - Approach best satisfies performance requirements, addresses ISS resource constraints and provides best scientific return for funding
- **FCF employs innovative design solutions and cost-effective engineering approaches**
  - Fold out optics bench, modular diagnostics, quick latch for complex electronics and other design features improve performance and/or conserve ISS resources
  - Stereo lithography hardware prototyping, COTS hardware use reduce the cost of FCF
- **New technology is incorporated in the FCF**
  - Embedded web software technology and EPCU next generation technology switches improve the performance and reduce the cost of FCF.
- **The FCF design is modular and permits automated (or crew-tended) operations, as well as upgrades**
  - Highly modular design of FCF permits long life on-orbit facility capability for least ISS resources and reduces funding requirements
  - Automated operations key to performing research in ISS era

Summary

- **There is high commonality within the FCF system and sub-systems**
  - Identical racks, power controllers, computer technologies, control avionics, image acquisition and storage units, other FCF hardware and software
  - Significantly reduces the life cycle cost of the facility
  - Also permits multi-discipline use of FCF capabilities (i.e., fluids, combustion or other)

- **The SAR is needed to meet fluids/combustion SRED requirements within the resource constraints**
  - The SAR provides capabilities beyond the interim CIR and FIR racks
  - The SAR increases FCF performance and throughput to meet the SRED

- **The FCF transitions from an in-house development to the MRDOC prime contract in fiscal year 2000**
  - FCF was defined using GRC microgravity in-house expertise and heritage
  - MRDOC Exhibit 1 completes the FCF development as a prime, fixed price contract

- **All of this has been a success**
  - Best approach to meet microgravity research goals for fluids and combustion science during ISS era.